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The Effects of Parallel Highway Noise Barriers

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ABSTRACT

The effect of parallel highway noise barriers (opposing barriers on both sides of a highway facility) was quantitatively evaluated using principles of geometrical acoustics. Image sources were employed to account for multiple reflections off barrier walls. Numerical calculations were performed using the FHWA highway noise prediction program, STAMINA 1.0.

Results indicate that the effect of parallel barriers can be substantial. Under certain conditions, the existing pre-construction sound levels can actually be increased (rather than reduced) by erecting vertical sound reflecting parallel barriers. The degradation effect of vertical barriers can be considerably reduced or eliminated by inclining barrier surfaces away from the highway. The degree of barrier wall inclination should be at least 3° or 5°.

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1/ INTRODUCTION

Barrier insertion loss of single, edge-shaped highway noise barriers has been extensively investigated; reliable prediction methods are available and there is a general consensus of opinion regarding their effectiveness in typical highway applications (1). The situation is quite different in the case of parallel or dual barriers (opposing barriers on both sides of the highway facility). The role of multiple sound reflections between the opposing barriers has been entirely discounted by some investigators (2), while it has been considered to be highly significant by others (3).

Ontario Ministry of Transportation and Communications, along with other transportation agencies, has been retrofitting existing freeways with noise barriers. Ten highway sites have been retrofitted single barriers were built on three sites and parallel or partially parallel barriers were required on seven sites. A similar split is projected for the rest of the retrofit program, rendering the single barrier situation actually atypical. The objective of this paper is to draw attention to the effect of parallel barriers and to quantify this effect for a typical highway situation.

In North America, the effect of parallel barriers was first introduced into a readily available highway noise barrier prediction method in 1976, in the form of a nomograph (3). The nomograph was based on the work of Pejaver and Shadley, (4) who employed acoustical scale modelling and geometrical acoustics to evaluate the effect of parallel barriers. However, the effect of parallel barriers has not yet become a part of common highway noise prediction models (5, 6).

2/ METHOD OF ANALYSIS

Analytical methods describing a reverberant field of a stationary point source in long, narrow spaces (7, 8) are not

readily adaptable to the problem at hand; not only do we have to deal with a line source, or a series of moving point sources located within the corridor, we must also model sound propagation and diffraction outside the corridor walls. The situation can be simplified by assuming that the effect of nonspecular reflections (sound scattered by barrier irregularities or highway vehicles within the opposite barriers) is negligible and by employing image sources to account for the effect of sound reflection off barrier walls. The numerical solution can then be obtained by utilizing existing computerized highway noise pre- diction models. This approach was used in this study by utilizing a recently developed FHWA prediction program STAMINA 1.0 (9).

The frequency of 500 Hz was chosen for the traffic noise source in the analysis since this frequency often dominates A-weighted traffic noise spectra (10). This choice allows the calculated sound levels to be considered as being in dBA. The height of the source was assumed to be 1.5 m above the pavement surface, corresponding to a highway traffic flow containing about 10% trucks.

To include the effect of multiple reflections, a number of image roadways were constructed and included in the computer program input. The program automatically accounts for distance attenuation (including atmospheric absorption) and barrier diffraction attenuation of sound emitted by the original, as well as by the image roadways, reducing the problem to a single barrier situation. The method of constructing image sources (image roadways) is illustrated for the first two reflections in Figure 1.

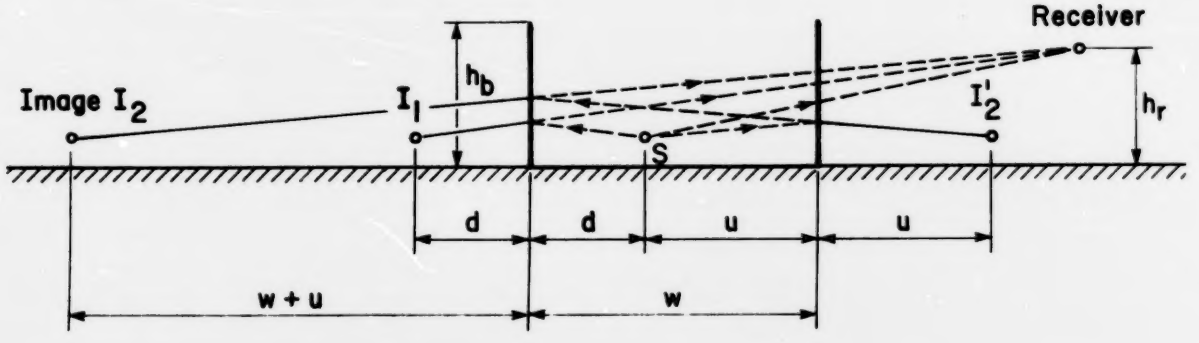

Figure 1/ Construction of Image Sources

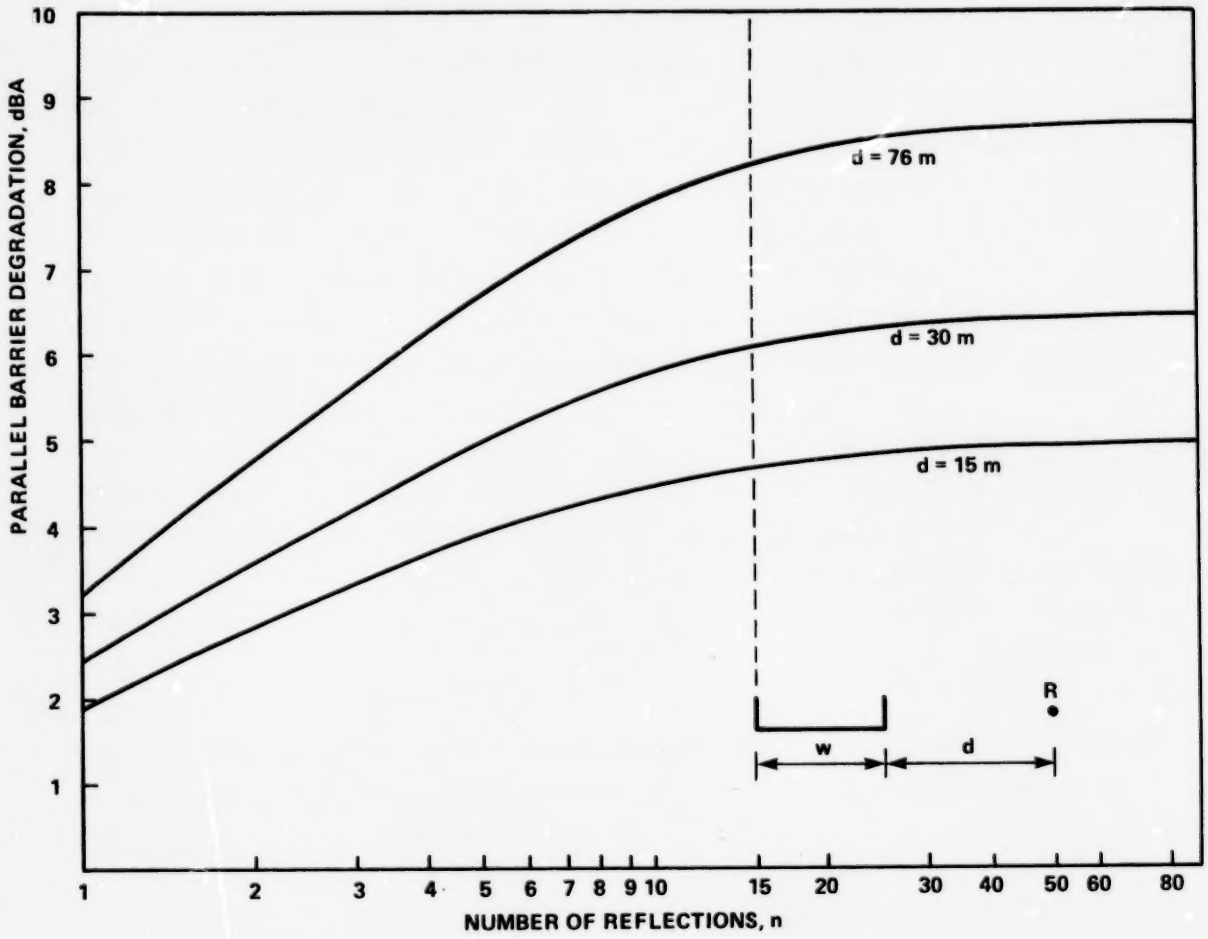

Figure 2/ Parallel Barrier Degradation Versus Number of Reflections
Height of barriers 4.5 m; distance between the barriers, w = 36.5 m, receiver is 1.5 m above the ground plane and distance d behind the barrier; sound absorption coefficient of barrier surfaces, $\alpha = 0.05$.

The number of reflected waves originating from image sources which can reach a receiver depends on the receiver's location relative to the barrier top. While an infinite number of reflections exists for receivers located in the region below the barrier top ($h_r < h_b$ in Figure 1), only the first 15 images were included in the analysis for practical purposes.

The effect of the number of reflections (image sources) included in the analysis is illustrated in Figure 2 for a barrier geome-

try used subsequently for more detailed analysis. The parallel barrier degradation shown on the ordinate of Figure 2 is the reduction in the single barrier insertion loss due to the presence of the opposite barrier. According to Figure 2, the degradation asymptotically increases as more and more reflections are accounted for. However, the contribution of the omitted reflections (reflections 16 to infinity) to the parallel barrier degradation was found to be smaller than 10% of the contribution provided by the first 15 reflections. This applies even for highly reflective barrier surfaces, and for large distances behind the barrier.

The number of reflections used in the analysis of receivers located above the barrier top ($h_r > h_b$) ranged from 0 to 15. To be included in the calculation, the reflected wave must have reached the opposite barrier at least 0.6 m below the barrier top.

The reflected waves are also attenuated by absorption of barrier surfaces. The sound absorption coefficient for multiple reflections, α_m, was defined:

$\alpha_m = \alpha^j$, where

α = "simple" absorption coefficient. Assumed identical for both barrier surfaces and independent of the angle of incidence.

j = number of reflections.

For the image sources, the original sound power of the source was reduced in proportion to α^j .

3/ RESULTS

3.1/ Vertical Barriers

The degradation effect of parallel barriers is illustrated in Figure 3, employing attenuation contours developed for 4.5 m high barriers, 36.5 m apart. This corresponds to a 6-lane freeway facility situated on flat terrain. The sound absorption coefficient of barrier surfaces was assumed to be 0.05, i.e. barriers were reflective. The contours in Figure 3 were developed for two ground cover types between the highway and the receivers

(a) soft, absorptive, ground, $\alpha = 0.5$ (α is defined in Reference 5), corresponding to the before-barrier sound attenuation rate of 4.5 dBA per distance doubling; and
(b) hard ground, $\alpha = 0.0$, corresponding to the before-barrier attenuation rate of 3.0 dBA per distance doubling. When the barrier is in place, the program STAMINA 1.0 assumes 3.0 dBA attenuation rate per distance doubling, regardless of the pre-barrier ground type, due to the "apparent" shift of the noise source to the top of the barrier.

For each ground type, isodecibel contours show the single barrier field insertion loss, Δs (Figures 3a and 3d); the barrier attenuation degradation due to the erection of the opposite barrier, Δd (Figures 3b and 3e) and the net field insertion loss for a parallel barrier situation, $\Delta s - \Delta d$ (Figures 3c and 3f). It may be noted that the parallel barrier degradation shown in Figures 3b and 3e is independent of the ground cover behind the barriers. Thus Figures 3b and 3e should be identical. The small differences between Figures 3b and 3e were caused by an independent separate construction of isodecibel lines using the same numerical data.

The predicted degradation of the single barrier attenuation due to the erection of the opposite barrier is quite dramatic, particularly when the ground between the highway and the observer is absorptive. For example, Figure 3f indicates that no net insertion loss is produced by the 4.5 m high reflective

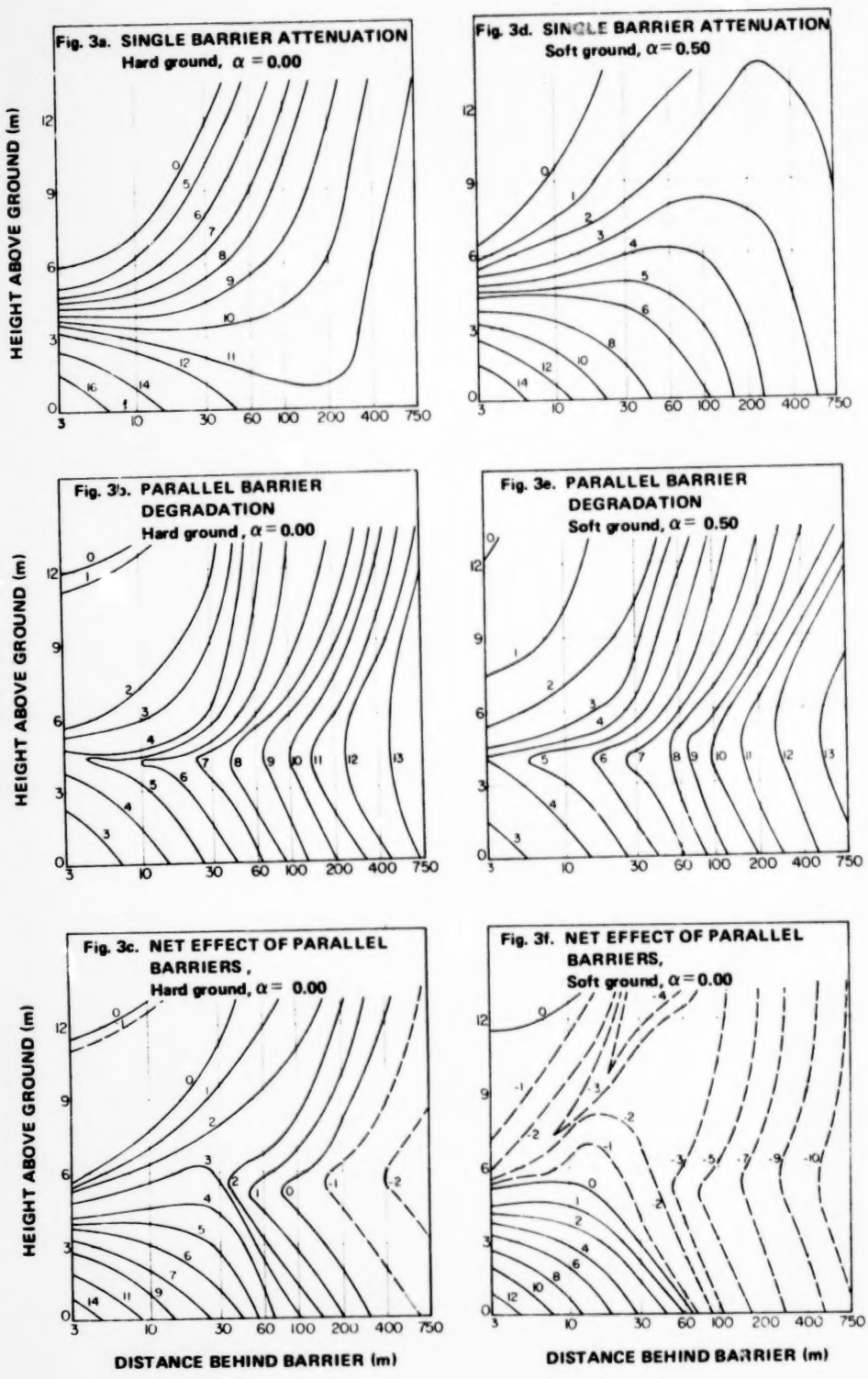
Fig. 3a. SINGLE BARRIER ATTENUATION
Hard ground, α = 0.00
Fig. 3d. SINGLE BARRIER ATTENUATION
Soft ground, α = 0.50
Fig. 3b. PARALLEL BARRIER DEGRADATION
Hard ground, α = 0.00
Fig. 3e. PARALLEL BARRIER DEGRADATION
Soft ground, α = 0.50
Fig. 3c. NET EFFECT OF PARALLEL BARRIERS,
Hard ground, α = 0.00
Fig. 3f. NET EFFECT OF PARALLEL BARRIERS,
Soft ground, α = 0.00
HEIGHT ABOVE GROUND (m)
DISTANCE BEHIND BARRIER (m)
3 10 30 60 100 200 400 750

Figure 3/ Barrier Attenuation Contours, dBA, Showing the Effect of Parallel Barriers
Height of Barriers 4.5 m; Distance Between the Barriers 36.5 m, Sound Absorption Coefficient of Barrier Surfaces 0.05.

barriers for receivers 40 m behind the barrier; furthermore, at a distance of 200 m behind the barrier, the net field insertion loss is negative, indicating a predicted increase of 6 dBA over the condition with no barriers. The net field insertion loss of the reflective parallel barriers situated on the hard ground, (Figure 3c), is equally affected by the presence of the opposite barrier. However, the net insertion loss is considerably higher than for the barriers on soft ground due to the higher single barrier attenuation. Nevertheless, Figure 3c indicates no net insertion loss for receivers 300 m or more behind the barrier.

Even though the potential degradation effect of reflective parallel barriers is considerable, it is still rather difficult to verify by field measurements. The degradation effect increases with the distance from the barrier (Figures 3b and 3e). The sound levels at a location of say 100 m behind the barrier (usually also shielded by one or two rows of houses) are not solely governed by highway noise but are influenced to a considerable degree by highly variable community noise sources (e.g. local traffic, children playing) and environmental factors (e.g. wind speed and direction).

In recent studies in which field acoustical performance of parallel highway noise barriers was evaluated (11, 12), it was found that the effect of parallel barriers may not be as significant as the application of geometrical acoustics would suggest. This is due to the presence of large reflecting surfaces at these sites (houses, parapet walls, highway vehicles) before as well as after barrier construction. Thus, the presence of the large reflecting surfaces further complicates the acoustic performance evaluation of parallel highway noise barriers. Certainly, more field studies are required.

3.2/ Inclined Barriers

Previous scale modelling studies have suggested that inclined noise barriers (barriers with faces sloped away from the highway) could reduce or even eliminate the degradation effect of parallel vertical barriers (13). To test their effectiveness, a quantitative evaluation of inclined barriers was also performed using the methodology described in Section 2.

Typical results are shown in Figure 4b, which relates barrier insertion loss to the degree of barrier inclination. The parallel barriers analysed have sound reflecting surfaces and protect receivers situated above soft ground. The receiver positions evaluated are schematically shown in Figure 4a.

According to Figure 4b, the parallel barrier insertion loss generally increases with the increase of inclination angle, until the angle of inclination reaches about 5°. Then for larger angles, the insertion loss slightly declines, due to the reduction in the barrier reflective height. The effect of barrier wall inclination depends on the barrier geometry and on the receiver location. It appears that for the barrier and receiver geometry evaluated, the optimal angle of inclination is about 5°.

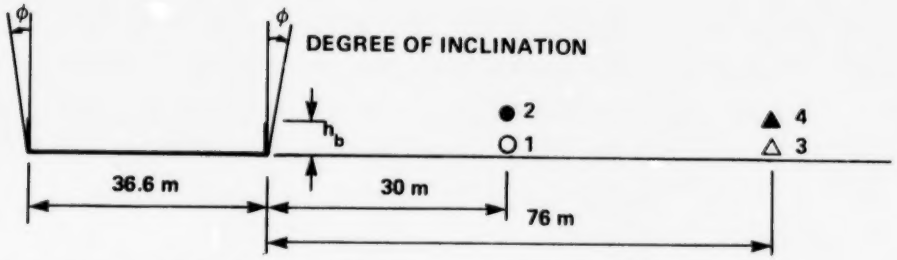

Figure 4a/ Sketch Showing Position of Locations Analysed
Inclined barrier height (h_b cos ϕ) was constant at 4.6 m (15 ft); locations 1 and 3 are 1.2 m above ground, locations 2 and 4 are 6 m above ground.

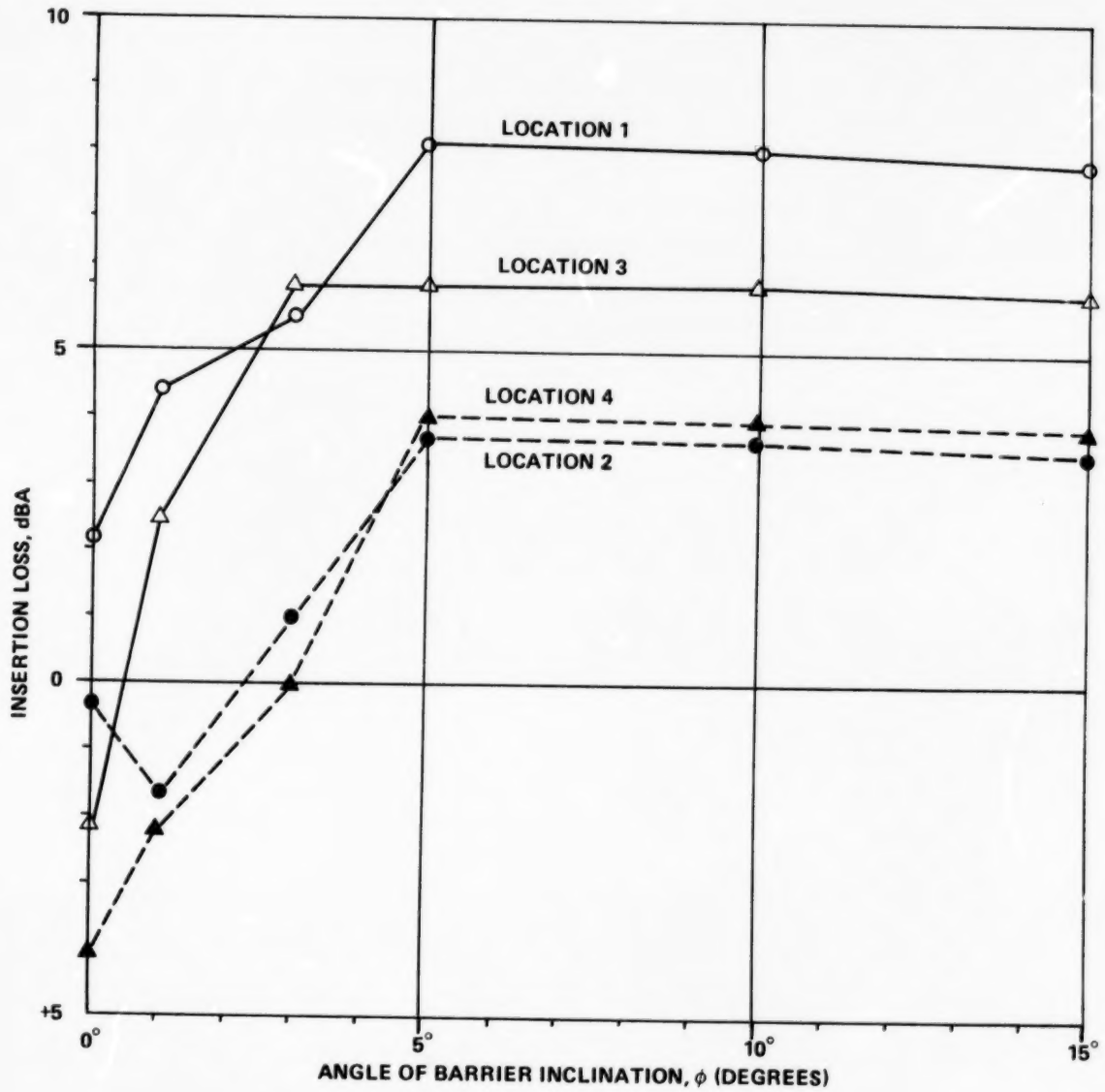

Figure 4b/ Effect of Barrier Inclination on Insertion Loss
Locations are defined in Figure 4b. Sound absorption coefficient of barrier surfaces, $\alpha = 0.05$; barrier protects soft ground (4.5 dBA per distance doubling)

CONCLUSIONS

1/ Noise sensitive land uses exist more often on both sides of highway facilities rather than on a single side only. Thus, the case of parallel highway noise barriers may actually represent a typical case of barrier arrangement.

2/ The impact of parallel barriers can be substantial, resulting in higher sound levels for a parallel barrier situation than for the free field situation.

3/ The degradation effect of opposite barriers can be considerably reduced or eliminated by using barriers with sound absorptive surfaces, or by inclining barrier surfaces by at least 3° or 5° away from the highway.

4/ Analytical results presented herein should be further verified by field measurements.

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